

Final Report
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Large Scale Electromagnetic Computation on Nonlinear
Optical Systems: Hardware and Software Augmentation

Arizona Center for Mathematical Sciences
Department of Mathematics
University of Arizona
PI: J.V. Moloney

The award of \$215,000 made under the DURIP '98 initiative went towards the purchase of an ONYX2 Silicon Graphics rack system with an internal graphics engine and 8 256MHz CPUs. This system was chosen as it provided state-of-the-art graphical visualization and computing capabilities and offered a cost-effective upgrade route. The rack system is directly linked to an earlier ONYX2 system obtained under a previous DURIP award. The in-house supercomputing engine has provided a significant boost to our AFOSR-funded research projects. The latter include the contract, "High Speed Modulation, Beam Steering and Control of Spatiotemporal Chaos in Semiconductor Lasers", (AFOSR 49200-97-1-0002), and AASERT grants, "Femtosecond Pulse Interactions with Nonlinear Interfaces", (AFOSR F49620-96-1-0311); and "Interactive Nonlinear PDE Solvers", (AFOSR F49620-97-1-0451). Our contract research is driven by large-scale computation in nonlinear optics areas of direct interest to Air Force Laboratory scientists. Interactions and collaborations exist with Air Force scientists at the Air Force Research Laboratory (AFRL/DELO), Kirtland AFB who are working under the High Power Semiconductor Laser Technology (HPSLT) program. Our projects provide theoretical input and simulation backup to their ongoing experimental efforts on high brightness semiconductor laser sources. Direct collaborations also exist with the Nonlinear Optics Group at the Air Force Research Laboratory. The effort here is focused on feedback-induced instabilities in multimode semiconductor lasers, synchronization of chaotic semiconductor lasers and message encoding in chaotic signals. The significantly increased computing capacity resulting from the DURIP award has enabled us to tackle the following major problems.

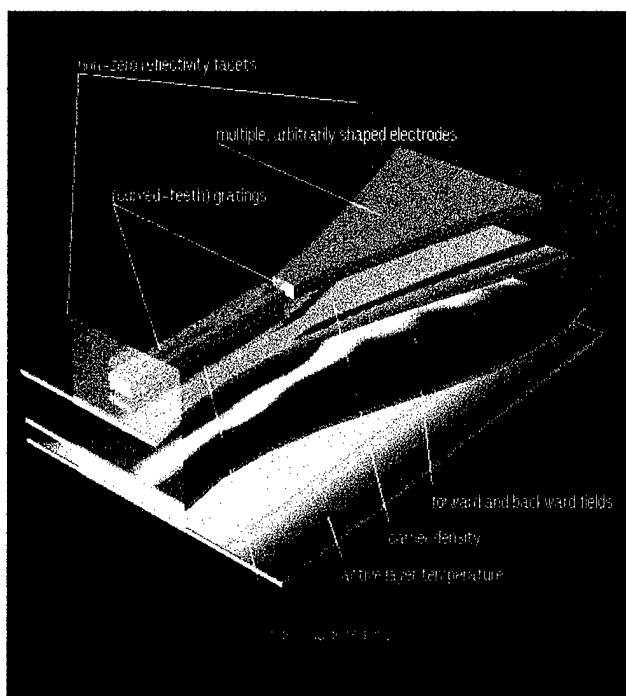
Structural Dependence of the Linewidth Enhancement Factor:
A Full Microscopic Many-body Calculation.

Compute for the first time, the full semiconductor response function from a first-principles microscopic theory including the Quantum Well structure, the barrier and GRINSCH regions.

Previously, only the semiconductor gain spectra could be computed by taking into account the Quantum Well states - this represented a major computation and that problem was only solved over one year ago. We used a semi-phenomenological approach at the time to include the barrier state contributions. The details of the structure outside the QW have a profound influence on the magnitude of the Linewidth Enhancement Factor and this latter quantity determines the strength of the filamentation instability that degrades the performance of high power semiconductor devices. Being able to control the magnitude of this factor is therefore critical to designing new generations of bandwidth-limited short pulse and/or high brightness semiconductor amplifiers and lasers. The new SGI ONYX2 machine allowed significantly enhanced throughput and efficiency in our gain calculations that were extended to include many valence and conduction non-resonant bands. We obtained the first quantitative agreement with experimentally measured gain/index and linewidth enhancement factor spectra for a variety of QW laser structures with varying well and barrier widths. The measurements were carried out by Stohs and Bossert at AFRL [1]. Our accomplishments in this area have led to consultations with laser engineers at Opto Power Corporation, a leading manufacturer of high power diodes, with researchers at the Philips Research Optoelectronics Group in Eindhoven, The Netherlands, with Osram (Germany) and with Hamamatsu Photonics, Japan.

An Interactive Supercomputing-based Simulator for High Brightness Laser Design

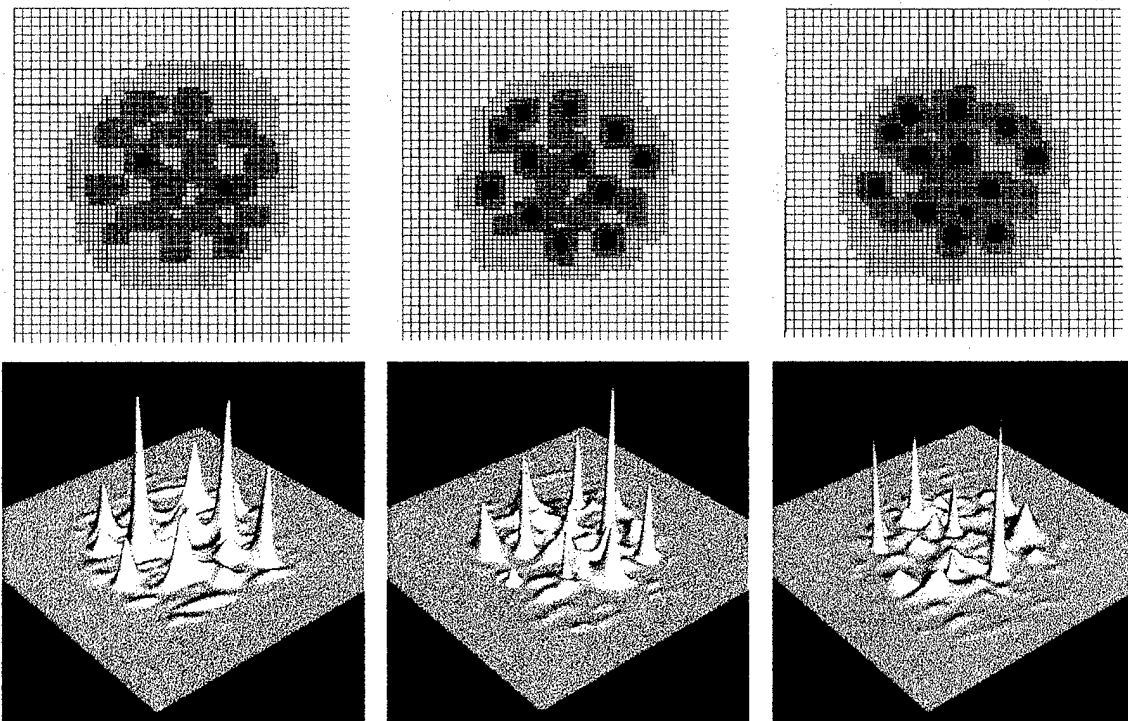
We have been able to study, for the first time, the complicated interplay between unavoidable residual optical feedback and intensity filamentation instabilities in monolithically integrated Master Oscillator Power Amplifier Lasers. This study requires that we resolve the full space and time development of the counterpropagating electromagnetic fields and the total carrier density through this multi-section complex structure. Our major conclusion is that these devices are unlikely to be useful unless one operates the Power Amplifier current below its value for spontaneous lasing. For an output facet reflectivity, $R=0.05\%$ the threshold is around 0.8 A and the output power is in the hundreds of milliwatts. We have been able to use the additional computational power to build a truly interactive simulator for a broad variety of high brightness devices. This simulator runs most efficiently, in parallel, over 8 CPUs on our SGI ONYX2 machine. The parallel scale up in performance has been particularly impressive. The picture on the right is a schematic layout of a typical high brightness device simulation. This shows a MOPA laser with the top layer showing the separate contacts on the master oscillator (MO) and power amplifier (PA) indicated in brown. Two gratings are placed at both ends of the MO in order to build a DBR section



that acts as a longitudinal mode filter. Beneath this layer lies a contour rendering of the carrier density distribution throughout the active layer. The dark stripes along the linearly expanding flare are regions of high unsaturated carrier. These are available for gain for back reflected light even though the output facet reflectivity is only 0.0005. We have now implemented current and refractive index profiling in order to suppress these unsaturated carrier regions and increase the overall brightness of the device. The lower layers depict the light intensity and active layer temperature distributions, respectively.

High Power Femtosecond Atmospheric Light Strings

Provide the capability to explore for the first time the physical mechanism that allows high power femtosecond duration laser pulses to form a self-guiding channel in air via the combined effects of critical self-focusing and weak plasma generation. This phenomenon promises important applications in lightning control, LIDAR, remote sensing and energy delivery. This problem is extremely challenging computationally as the physical phenomenon is highly explosive, involving simultaneous compression in space and time. Even with the computational facility provided by the earlier DURIP '97 award, we were still restricted to studying radial symmetry geometries. The new system has greatly enhanced our simulation capability allowing us to go to a full 3D+time simulation. This problem is extremely complex computationally due to the explosive chaotic light intensity spikes and accompanying plasma generation with sharp gradients due to the optical breakdown of air. We had to develop a parallel, adaptive mesh algorithm to resolve these fine scale details simultaneously in space and time. The bottom pictures below depict the light intensity filaments appearing at three different time slices within the femtosecond pulse. The top pictures are the corresponding grid levels needed to resolve the structures immediately below.



The scale up in parallelism is even more impressive for this problem and closely follows the theoretical Amdahl's Law.

Novel SHG for Femtosecond Pulses

The augmented computing facility has allowed us to access the fully 2D and 3D vector Maxwell ultrashort pulse regime. In addition, we have been able to explore novel nonlinear effects due to ultrashort light pulse interactions with materials [2]. At the vector Maxwell level, one is forced to resolve the underlying optical carrier wave and this places a significant restriction on the type of problem that can be solved. We have made significant progress on a series of 1D and 2D problems and these results are reported under our main contract and the AASERT annual progress reports. We are planning to use the new facility to study the interaction of intense femtosecond-duration linear and nonlinear light pulses with random scattering media in order to evaluate the feasibility of nonlinear pulses penetrating through atmospheric obscurants.

Double Clad Fiber Amplifiers and Lasers for High Brightness Applications

We have begun to initiate the development of a fiber amplifier/laser model in response to the needs of the group at AFRL (DELO). The huge gain bandwidth of the doped fiber amplifiers and lasers, encompass thousands of longitudinal modes and leads to complex spatiotemporal behavior. We are currently evaluating ray vs. wave optics approaches to studying the coupling of incoherent pump light into a doped amplifier/laser core with the view to optimizing the pump coupling efficiency.

- [1] J. Hader, D. Bossert, J. Stohs, W.W. Chow, S.W. Koch, and J.V. Moloney, *Applied Physics Letters* **74**(16), pp. 2277-2279
- [2] M. Mlejnek, J.V. Moloney, E.M. Wright, and N. Bloembergen, *Physical Review Letters*, **83**(15), pp. 2934-2937.

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